NBSIR 84-2839

Mechanical Properties of A Leaded, Resulfurized, Rephosphorized Steel in Various Thermo/Mechanical Conditions

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Metallurgy Division
Washington, DC 20234

January 1984

Final Report

Issued March 1984

Prepared for
United States Coast Guard
Department of Transportation
Washington, DC 20590

NBSIR 84-2839

MECHANICAL PROPERTIES OF A LEADED, RESULFURIZED, REPHOSPHORIZED STEEL IN VARIOUS THERMO/MECHANICAL CONDITIONS

J. G. Early

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Metallurgy Division
Washington, DC 20234

January 1984

Final Report

Issued March 1984

Prepared for
United States Coast Guard
Department of Transportation
Washington, DC 20590

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

INTRODUCTION

The National Bureau of Standards (NBS) was requested by the U.S. Coast Guard, Department of Transportation to conduct a limited metallurgical evaluation of samples of a leaded, re-sulfurized, re-phosphorized freemachining steel. This class of steel is often used for applications in which substantial metal is removed by machining operations. Subsequent joining operations, such as brazing, are also often specified.

Machinability is strongly influenced by such mechanical properties as strength, hardness, and ductility.[1,2]* In carbon steels, these properties are controlled primarily by the carbon content. Annealed low carbon steels (less than 0.15% C) often do not have good machining characteristics because of poor chip forming behavior due to low strength. Improved machinability can be achieved through additional processing operations such as heat treating or cold working. Higher carbon steels (greater than 0.35% C) exhibit satisfactory chip characteristics, but cause greater cutting tool wear as a result of substantially higher hardness. If cutting speed is reduced to improve tool wear, then surface quality often decreases. To improve the machinability of the higher carbon pearlitic steels, heat treating to partially spheroidize the microstructure is necessary.

An alternative approach to these additional costly processing steps is to select a modified chemical composition to enhance machinability while maintaining the desired mechanical properties. Higher concentrations of sulfur (re-sulfurized steels), phosphorous (re-phosphorized steels), and lead (leaded steels), whether added individually or in combination, enhance steel machinability. These additions result in increased machining speed or improved surface finish through their influence on chip formation and cutting tool lubrication. The effect of increased sulfur content (up to 0.35%) is primarily through control of the shape, size, and distribution of manganese sulfide inclusions. These inclusions favor broken rather than continuous chips and act as a lubricant to prevent chip adherence on the tool. Increased phosphorous levels (up to 0.12%) strengthens the steel (ferrite strengthener) and aids chip break-up. Upper limits for phosphorus additions are required, however, since increased hardness and strength eventually lowers machinability and leads to excessive of tool wear. Lead, although essentially insoluble in both liquid and solid steel, can be added without gross segregation in amounts up to 0.35% as a result of modern steelmaking practice. The lead, usually found as a fine dispersion associated with the manganese sulfide inclusions, acts in a similar manner to sulfur but does not degrade room temperature mechanical properties.

The purpose of this metallurgical evaluation was to determine the mechanical properties of one grade of free-machining steel in bar form in several thermo/ mechanical conditions and to correlate the measured

---

*Numbers in brackets refer to references listed at the end of the report.

mechanical properties with its microstructure. The effect of subsequent thermal processing, e.g. brazing, on mechanical properties was also investigated.

MATERIAL

The material selected for this study was reportedly produced to American Iron and Steel Institute (AISI) grade 12L14. The nominal specified composition for this grade is: carbon 0.15% max; manganese 0.85-1.15%, sulfur 0.26%-0.35%; phosphorus 0.04-0.09%; and lead 0.15-0.35%.[3,4] The as-received samples were in the form of eight foot (2.44 m) lengths of bar stock cut from longer lengths. The bar stock samples were supplied in the following sizes and reported thermo/mechanical conditions: 3/4 inch (19 mm) diameter, cold finished hexagonal bars; 3/4-inch (19mm) diameter, hot rolled round bars; 1-1/2 inch (38 mm) diameter, cold finished hexagonal bars; and 1-1/2 inch (38 mm) diameter, hot rolled round bars.

Flat rolled steel products are classified as either hot rolled or cold finished.[5] Hot rolled products are produced entirely at elevated temperatures with the final thickness or diameter of carbon steels achieved at temperatures above the lower transformation temperature. Cold rolled products are actually only cold finished because most of the size reduction operations are carried out hot as for hot rolled products. Generally, cold finished products receive enough cold working in the final rolling operations to improve the surface finish and affect the mechanical properties of the final product.

In order to investigate the role of a subsequent thermal processing operation, portions of one length of 1-1/2 inch (38 mm) cold finished bar stock were subjected to the thermal cycle of a commercial brazing process. In this report, these samples will be referred to as being in the cold finished/heat treated condition. Individual pieces of bar stock (without the brazing alloy) were placed along side actual components passing through a continuous brazing furnace.[6]

The brazing furnace was a four zone furnace, 42 feet (13 m) long. The conveyor belt moved at a speed of six inches/minute (15 cm/minute). A slightly reducing atmosphere was maintained throughout the furnace, although only the second zone 4 feet (1.2 m) long and the third zone 2 feet (0.6 m) long were directly heated. The zones were not separated so heating also occurred throughout zone 1. The second zone was controlled at 2100 F (1149 C) and the combination of zone length, belt speed, and temperature caused the metal parts to reach this temperature at the end of zone 2 without a significant soaking period. The third zone was set at a lower temperature so that slow cooling occurred before entering the unheated fourth zone where the parts cooled to about 150 F (66 C). The entire cycle took approximately 1 hour 24 minutes to complete.

EXPERIMENTAL PROCEDURE

Tensile properties and standard Charpy V-notch impact properties were determined, hardness surveys performed, and microscopic observations made on each bar stock size in each thermo/mechanical condition. Longitudinal specimens (specimen axis aligned parallel to bar axis) were prepared for the tensile tests and Charpy impact tests.

Metallographic Analysis and Hardness Survey

Representative photomicrographs were obtained from selected polished and etched areas oriented parallel and perpendicular to the bar axis of each type of bar stock. The ferrite grain size was measured in accordance with the circular intercept method from ASTM E112-74, Intercept Method.

Rockwell B hardness measurements were made on specimens adjacent to the metallographic specimens and correlated with the microstructure of each bar sample. Hardness measurements were obtained on transverse sections, from surface-to-surface across the bar diameter.

Mechanical Property Testing

Longitudinal test specimens for both tensile tests and Charpy impact tests were taken as closely as possible from the quarter diameter positions in each type of bar stock. A schematic of the tests specimen orientation and location followed in this study is shown in Figure 1. A broach was used to create a uniform and reproducible V-notch in the Charpy specimens, and the notch was oriented (in the specimen) approximately facing the center of the bar. The tensile specimens, standard 0.250 inch (6.3 mm) in diameter with a 1-inch (25.4 mm) gage length, and standard 0.394 inch (10 mm) Charpy V-notch specimens were tested, respectfully, in accordance with ASTM A370-73, Mechanical Testing of Steel Products, and ASTM E23-72, Notched Bar Impact Testing of Metallic Materials.

RESULTS AND DISCUSSION

Metallographic Analyses and Hardness Measurements

Representative photomicrographs taken at low magnification on longitudinal and transverse planes of unetched samples of the as-received bars are shown in Figure 2. Numerous thick and thin inclusions, primarily manganese sulfide, can be seen, and this observation is consistent with the higher permitted sulfur content for this steel. The fine lead droplets are not observed at this magnification. This inclusion microstructure is contrasted with that found in a steel of similar manganese content (1.15%) but a much lower sulfur content (0.017%), Figure 3. In the low sulfur steel, the manganese sulfide inclusion are all thin and the inclusion volume fraction is lower than for the high sulfur steel used in this study.

Representative microstructures of each as-received sample are shown in the etched condition in Figure 4. The microstructure of the sample of the 1-1/2 inch (38 mm) bar in the cold finished/heat treated condition is shown in Figure 5. The microstructures are typical of low-carbon steels and consist primarily of proeutectoid ferrite with small amounts of pearlite. The longitudinal photomicrographs of both the hot rolled and the cold finished bars show the ferrite grains to be equiaxed and the pearlite and inclusions aligned parallel to the bar axis. The pearlite distribution anisotrophy (often called banding in plate products) is a result of chemical segregation in the original ingot which has now been elongated parallel to the bar axis as a result of the bar forming operations.

The measured ferrite grain sizes are reported in Table I. Ferrite grain sizes is strongly influenced by the prior austenite grain size, the cooling rate through the transformation temperature, and any subsequent thermo/mechanical processing after the initial austenite-to-ferrite/pearlite transformation. The absence of any evidence of elongated ferrite grains in either of the sizes of hexagonal bars suggests that the cold worked bars were re-heated or stress relieved just before or after the final forming operation so that the ferrite grains recrystallized. Stress relieving of cold finished bars is often done to change the size and distribution of residual stresses.

The observations that both of the small diameter bars, 3/4 inch (19 mm) hexagonal and round, had almost the same ferrite grain size, and both of the larger diameter bars 1-1/2 inch (38 mm) hexagonal and round, had the identical but somewhat larger ferrite grain size, indicated that the hot finishing temperatures for both sizes of both hexagonal and round bars were probably similar. The somewhat larger grain size in the larger diameter bars probably resulted from a slower cooling rate through the transformation temperature due to their larger mass. The grain size for the cold finished/heat treated 1-1/2 inch (38 mm) bar condition was the same as the other 1-1/2 inch (38 mm) bars suggesting that the brazing cycle heat treatment did not cause any change in microstructure.

The results of the hardness measurements are shown in Table II. The average Rockwell B hardness values for the cold finished bars was twenty-two hardness points higher for each size than for the hot rolled bars HRB 86 vs. 64 for the smaller diameter bars, HRB 81-1/2 vs. 60 for the larger diameter bars. The average hardness value for the 1-1/2 inch (38 mm) bar samples in the cold finished/heat treated condition, HRB 61-1/2, is similar to the values for the hot rolled bars, HRB 64 and 60, and considerably lower than the values for the cold finished bars, HRB 86 and 81-1/2. This indicates that the brazing cycle heat treatment was similar in effect to a process anneal or stress relief heat treatment.

The hardness profiles for the two sizes of cold finished bars are quite uniform except for the values measured nearest the bar surfaces

which are slightly higher, possibly due to a final cold forming operation that work hardened the surface slightly. The hardness profiles for the two sizes of hot rolled bars were also very uniform except for the values nearest the bar surface in the smaller bar which are slightly lower. This may have resulted from some decarburization of the surface.

Tensile Properties

The measured tensile properties of each bar size and condition are given in Table III. The average ultimate tensile strength and yield strength values for the 3/4 inch (19 mm) bars, in both the cold finished and hot rolled conditions, were somewhat higher than for the 1-1/2 inch (38 mm) bars finished to the same conditions. These differences, which appear to be a function of bar diameter, are consistent with the grain size measurements and the hardness profile measurements. The smaller diameter bars, in each thermo/mechanical condition, had a finer ferrite grain size (resulting in higher yield strength) and higher average hardness values (resulting in higher ultimate tensile strength) than the larger diameter bars.

The average ultimate tensile strength and yield strength values for the bars tested in the cold finished condition were substantially higher than for the bars tested in the hot rolled condition. The average ultimate-tensile strength values for the cold finished condition and the hot rolled condition for the 3/4" inch (19 mm) bars were 75.8 Ksi (522 MPa) and 58.8 Ksi (405 MPa), respectively, while the average 0.2% offset yield-strength values were 71.0 Ksi (489 MPa) and 43.0 Ksi (296 MPa), respectively. For the 1-1/2 inch (38 mm) bars, the average ultimate tensile strength values in the cold finished condition and the hot rolled condition were 73.9 Ksi (510 MPa) and 54.3 Ksi (374 MPa), respectively, while the average 0.2% offset yield-strength values were 68.6 Ksi (473 MPa) and 35.8 Ksi (247 MPa), respectively. For samples of the 1-1/2 inch (38 mm) bar in the cold finished/heat treated condition, the average ultimate tensile strength and 0.2% offset yield-strength values of 54.9 Ksi (378 MPa) and 32.9 ksi (226 MPa), respectively, are very close to the values (54.3 Ksi and 35.8 Ksi), for the 1-1/2 inch (38 mm) hot finished bar.

The ultimate-tensile-strength data can be compared with the hardness measurements. Using a reported [7] empirical relationship between hardness and ultimate tensile strength, the measured average hardness values of HRB 86 and HRB 81.3, respectively, for the 3/4 inch (19 mm) and the 1-1/2 inch (38 mm) cold finished bars correspond to ultimate-tensile strength values of 81 Ksi (558 MPa) and 75 Ksi (517 MPa), reespectively. The measured average ultimate-tensile-strength values of 75.8 Ksi (522 MPa) and 73.9 Ksi (510 MPa), respectively, are 6% and 1-1/2% lower than the predicted values. The measured average hardness value of HRB 64 for the 3/4 inch (19 mm) hot rolled bar corresponds to an ultimate-tensile-strength value of 56 Ksi (386 MPa). The measured average ultimate-tensile-strength value of 58.8 Ksi (405 MPa) is 5% above the predicted value. The measured average hardness value of HRB

60 and HRB 61.5, respectively, for the 1-1/2 inch (38 mm) hot rolled bar and the 1-1/2 inch (38 mm) cold finished/heat treated bar fall below the lowest value (HRB 64, 56 Ksi) reported for the empirical hardness-tensile strength relationship and thus the equivalent ultimate tensile strength values would be below 56 Ksi. The measured ultimate-tensile-strength values of 54.3 Ksi (374 MPa) and 54.9 Ksi (378 MPa) are consistent with the predicted values of less than 56 Ksi (386 MPa). This generally good agreement between the empirically derived ultimate-tensile-strength values and the measured values (within $\pm$ 6%) is as good as can be expected for this type of correlation and confirms the expected trends between hardness and ultimate tensile strength.

The yielding behavior can provide further evidence as to the effect of cold work on mechanical properties. Sufficient cold work can lead to the elimination of a sharp yield point, increases in ultimate tensile strength and yield strength, decreases in ductility, and increases in the ductile-to-brittle transition temperature as measured by Charpy V-notch impact tests. Schematics of the typical stress-strain curves observed are shown in Figure 6. None of the specimens taken from either diameter of the cold finished bars exhibited a sharp yield point. All of the specimens from both diameters of the hot rolled bar exhibited sharp yield points with measurable upper and lower yield point values. The specimens from the cold finished/heat treated bar also exhibited upper and lower yield points.

The absence of sharp yield points in the cold finished specimens indicates that the cold work introduced by the final cold forming operation was sufficient to eliminate the yield point observed in the hot rolled condition and to increase substantially the yield strength. The re-appearance of a sharp yield point in the cold finished bar subjected to the brazing thermal treatment indicates that the thermal treatment was sufficient to remove the effects of cold work.

Calculated values of the yield strength/tensile strength ratio, σ_y/σ_u for the cold finished bars (0.94 and 0.93) illustrate the strong influence of the cold finishing process on increasing the yield strength when compared to the ratio for the hot rolled bars (0.73 and 0.66). The high (yield/tensile) ratio for the cold finished bars demonstrates the low capacity for work hardening in this condition. The bars in the hot rolled condition, however, can be work hardened considerably more. The average yield/tensile ratio (0.60) for the cold finished/heat treated samples is very close to the hot rolled values and indicates a complete recovery from the strengthening due to the cold finishing operations.

The average tensile ductility values as measured by percent elongation and percent reduction-in area for the 3/4 inch (19 mm) bars, in both the cold finished and the hot rolled conditions, were generally lower than for the 1-1/2 inch (38 mm) bars in the same conditions. These tensile ductility results (compared to the data for the larger diameter bars) are in agreement with the somewhat higher strength, higher hardness, and finer grain size reported for the smaller diameter bars.

The average tensile ductility values for both bar sizes in the cold finished condition were substantially lower than for both sizes in the hot rolled condition, e.g. percent elongation values for the cold finished samples were less than one-half that for the hot rolled samples. The average percent elongation and percent reduction-in-area values for the cold finished/heat treated samples of the 1-1/2 inch (38 mm) bar (38.3% and 64%, respectively) were very close to the values for the hot rolled bar (39.7% and 65%, respectively). This further confirms the recovery from the effects of cold finishing.

Impact Properties

The notched impact toughness properties as measured by the Charpy V-notch (CVN) impact test for each bar size and thermo/mechanical condition are given in Tables IV, V, and VI and Figures 7 and 8 for two widely used fracture criteria: energy absorption and shear fracture appearance (SFA).

Carbon steels generally exhibit a well-defined ductile-to-brittle temperature transition as measured by the temperature dependence of the fracture criteria. Brittle or cleavage fracture is observed at temperatures below the lower knee of the curves (Figures 7 and 8); ductile or shear fracture is observed at temperatures above the upper knee of the curves; and a mixture of ductile and brittle fracture modes are found in the temperature region between the two knees. The temperature transition regions for the cold finished bars and hot rolled bars are different regardless of bar diameter; further, for each thermo/mechanical condition, the temperature transition regions for the 3/4 inch (19 mm) bars are different than those of the 1-1/2 inch (38 mm) bars. These conclusions are illustrated in the SFA plot. The CVN transition region for the 3/4 inch (19 mm) and 1-1/2 inch (38 mm) cold finished bars extends from 0 F (-18 C) to +120 F (+49 C) and from 0F (-18 C) to +180 F (+82 C), respectively. The CVN transition region for the hot rolled bars extends from <-60 F (<-51 C) to +40 F (+4 C) and from <-60 F (<-51 C) to +100 F (+38 C), respectively. The CVN transition range for the cold finished/heat treated bar extends from -40 F (-40 C) to +120 F (+49 C). The Charpy V-notch ductile-to-brittle transition temperature of carbon steels, often characterized by the 15 ft-lb (20 joules) transition temperature or the 50 percent SFA transition temperature, is primarily controlled by the steel chemistry, (decreasing transition temperature with increasing manganese/carbon ratio), ferrite grain size (decreasing transition temperature with decreasing grain size), and the thermo/mechanical condition (increasing transition temperature with increasing cold work). In the present study, the steel chemistry is assumed to be similar for all samples. As shown in Figures 7 and 8, the thermo/mechanical condition has the major influence on the transition temperature. Both sizes of cold finished bars exhibit higher transition temperatures (lower toughness) than the hot rolled bars as a result of the effect of the cold work. The transition temperatures of the bars in the cold finished/heat treated condition falls in between the cold finished and hot rolled values. Further, for both toughness criteria, the smaller diameter bars in either the cold finished or the hot rolled condition

exhibit lower transition temperatures (higher toughness) than the larger diameter bars. This observation is consistent with the effect of increasing toughness with decreasing ferrite grain size.

The upper shelf energy absorption values for the 1-1/2 inch (38 mm) bars in both the cold finished and the hot rolled conditions (38 ft-lbs, 52 joules and 70 ft-lbs, 95 joules) are higher than the values measured for the 3/4 inch (19 mm) bars in the same conditions. Further, the upper shelf energy absorption values for the hot rolled bars (58 ft-lbs, 79 joules and 70 ft-lbs, 95 joules) are substantially higher than for the cold finished bars (31 ft-lbs, 42 joules and 38 ft-lbs, 52 joules). These observations are in agreement with the hardness data discussed earlier in this report where it was found that the hardness of the cold finished bars was substantially higher than for the hot rolled bars, and, for each thermo/mechanical condition, the smaller diameter bars exhibited higher hardness than the larger diameter bars. In addition, there is a direct relationship between the upper shelf energy absorption values and the measured yield strength; as the yield strength values increase, the energy absorption values decrease. This observation is in good agreement with studies reported for a wide variety of steels in various heat treated conditions, including carbon/ manganese steels. [8]

Visual inspection of the tested Charpy specimens revealed a change in fracture behavior in some hot rolled bar specimens tested at temperatures on the upper shelf plateau. As shown in Table IV, the upper shelf energy absorption plateau (67 to 72 ft-lbs, 91 to 98 joules) was reached in the temperature range of 72 F (22 C) to 123 F (31 C) for the 1-1/2 inch (38 mm) hot rolled bar. Similarly, 100 per cent SFA was attained over this same temperature range. A specimen tested at 164 F (73 C), however, did not fracture and exhibited an abnormally high energy absorption compared to the upper shelf plateau. Examination of the specimen (Figure 9a) revealed that a tensile stress overload bent the specimen with little or no evidence of crack propagation from the bottom of the V-notch. Further, the specimen exhibited splitting perpendicular to the V-notch and parallel to the long axis, in the principal bar deformation direction. This behavior indicated that a change in fracture mode occurred over the temperature range between 123 F (51 C) and 164 F (73 C).

The identical behavior was observed in specimens from the 3/4 inch (19 mm) hot rolled bar. The upper shelf energy absorption plateau (55 to 60 ft-lbs, 75 to 82 joules) and the 100 percent SFA were reached in the temperature range of 0F (18 C) to 32 F (0 C). Specimens tested above 55 F (13 C) did not fracture and exhibited abnormally large energy absorption values. Examination of these specimens (Figure 9b) revealed the same features as observed in the 1-1/2 inch (38 mm) specimen. One specimen from the 1-1/2 inch (38 mm) cold finished/heat treated bar also behaved in a similar manner. In this thermo/mechanical condition, however, greater variability in fracture behavior was found. Although two specimens were tested at 123 F (51 C), one specimen at 163 F (73 C), and one specimen at 209 F (98 C), only one of the specimens tested at 123 F (51 C) exhibited bending failure and splitting.

The energy absorption data from specimens exhibiting bending failure have no significance because the high energy absorption results from the bending of the test specimen, its ejection from the holding fixture, and the friction forces overcome as the specimen was pushed out of the Charpy test machine. These data are not shown in Figures 7 and 8. None of the specimens from the cold finished bars exhibited this behavior over the range of test temperatures.

SUMMARY

The results of the metallurgical evaluation of bar stock samples of AISI 12214 steel in two thermo/mechanical conditions, cold finished and hot rolled, illustrate the dominant role that the thermo/mechanical condition has on the resulting mechanical properties. The contributing effects of ferrite grain size and bar diameter on mechanical properties were small in comparison to the effects of cold work during the cold finishing operation. Cold finished bar stock samples subjected to a thermal brazing cycle (without the brazing alloy) develop mechanical properties that are very similar to those attained in hot rolled bars.

ACKNOWLDGEMENT

The author wishes to thank Mr. C. H. Brady for his contributions to the metallographic and grain size determination portions of this report. Special thanks to Mrs. Mary Wykes for her assistance in preparing the final version of this report.

REFERENCES

1. Metals Handbook, Vol. 1, Properties and Selection of Metals, 8th Edition, American Society for Metals, 1961, pp. 304-309.

2. Metals Handbook, Vol. 1, Properties and Selection: Irons and Steels, 9th Edition, American Society for Metals, 1978, pp. 572-578.

3. American Society for Testing and Materials Specification A108-81, "Standard Specification for Steel Bars, Carbon, Cold-Finished, Special Quality."

4. American Society for Testing and Materials Specification A576-81, "Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality."

5. The Making, Shaping and Treating of Steel, U.S. Steel Corporation, 1971, pp. 932-93.

6. Private Communication, W. Currie, Parker-Hannifin Corp., January 4, 1984.

7. Army-Navy Approximate Hardness Tensile Strength Relationship of Carbon and Low Alloy Steels, AN-QQ-H-201, 1943.

8. Gross, J. H., "The Effective Utilization of Yield Strength," J. Engr. Industry, ASME Paper No. 71-PVP-11, 1971.

Table I. Ferrite Grain Size Measurements

Condition	Diameter	Ferrite Grain Size[a]
Cold Finished	3/4 inch (19 mm)	8
Cold Finished	1-1/2 inch (38 mm)	7
Hot Rolled	3/4 inch (19 mm)	8-1/2
Hot Rolled	1-1/2 inch (38 mm)	7
Cold Finished and Heat Treated	1-1/2 inch (38 mm)	7

[a]Measured according to ASTM E112-74, Intercept Method

Table II. Hardness Profile Measurements

Rockwell "B" Scale

Condition	Bar Diameter	Hardness Values	Average Hardness
Cold Finished	3/4 inch (19 mm)	87,85-1/2,85-1/2,85,85,85,88	86
Cold Finished	1-1/2 inch (38 mm)	84,81,79,80,80,82,83	81.3
Hot Rolled	3/4 inch (19 mm)	61-1/2,65,66,67,65-1/2,63-1/2,61	64
Hot Rolled	1-1/1 inch (38 mm)	61,59,58,58-1/2,58,58,60	60
Cold Finished and Heat Treated	1-1/2 inch (38 mm)	61,61-1/2,62,62	61.5

Table III. Tensile Properties

Size and Condition	Spec. No.	Ultimate Tensile Strength, σ_μ Ksi	Ultimate Tensile Strength, σ_μ MPa	Yield Strength 0.2%, σ_Y Ksi	Yield Strength 0.2%, σ_Y MPa	$\frac{\sigma_Y}{\sigma_\mu}$	Upper Yield Point Ksi	Upper Yield Point MPa	Lower Yield Point Ksi	Lower Yield Point MPa	Elongation % 1 inch GL	Reduction In-Area %
3/4 inch (19 mm)	CT10	75.7	522	71.0	489	.94	NA		NA		---	---
Cold Finished	CT11	75.9	523	71.1	490	.94	NA		NA		17.1	53.3
	average	75.8	522	71.0	489	.94	NA		NA		17.1	53.3
1-1/2 inch (38 mm)	CT2	74.9	516	70.1	483	.94	NA		NA		15.1	54.7
Cold Finished	CT3	73.0	503	67.2	463	.92	NA		NA		16.9	57.2
	average	73.9	510	68.6	473	.93	NA		NA		16.0	56.0
3/4 inch (19 mm)	HT 10	58.9	406	43.3	298	.74	50.3	346	43.5	300	36.8	60.7
Hot Rolled	HT 11	58.6	404	42.8	295	.72	53.8	371	42.3	292	35.2	59.9
	average	58.8	405	43.0	296	.73	52.0	358	42.9	296	36.0	60.3
1-1/2 inch (38 mm)	HT1	54.4	375	36.0	248	.66	42.8	295	36.0	248	40.2	64.0
Hot Rolled	HT2	54.2	373	35.7	246	.66	42.8	295	35.7	246	39.2	66.0
	average	54.3	374	35.8	247	.66	42.8	295	35.8	247	39.7	65.0
1-1/2 inch (38 mm)	CT1	55.1	380	32.9	226	.60	39.6	273	32.9	226	37.6	64.5
Cold Finished and Heat Treated	CT4	54.6	376	32.9	226	.61	39.4	271	33.3	230	39.1	63.6
	average	54.9	378	32.9	226	.60	39.5	272	33.1	228	38.3	64.0

Table IV. Energy Absorption Data Summary

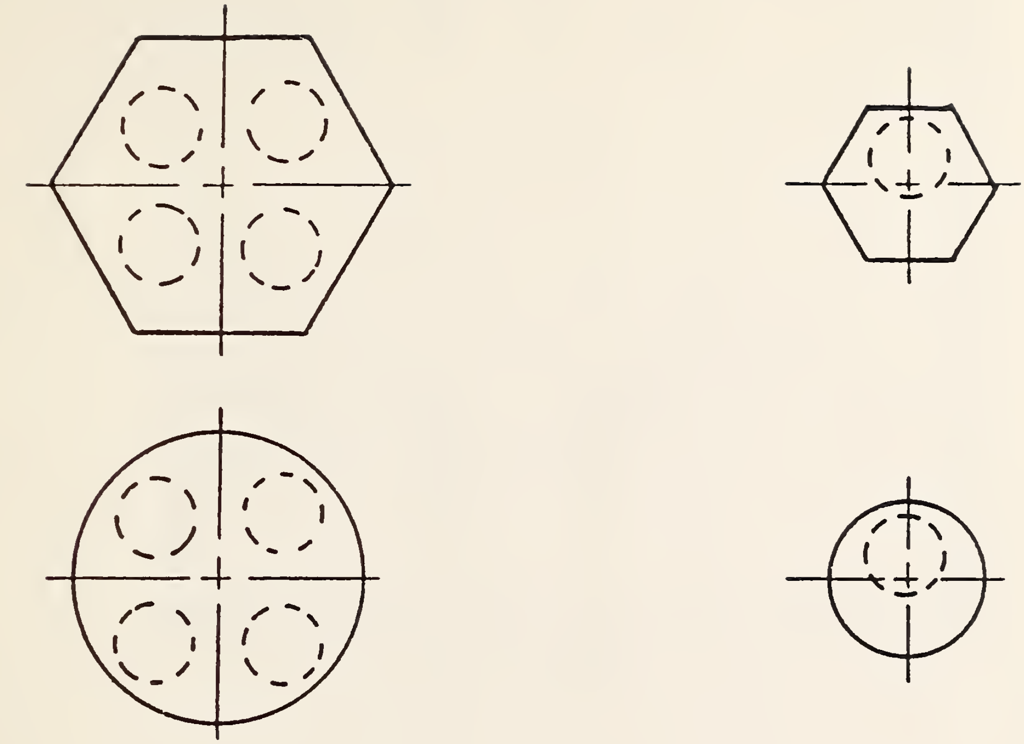
Test Temperature		3/4 inch (19 mm) Cold Finished		1-1/2 inch (38 mm) Cold Finished		3/4 inch (19 mm) Hot Rolled		1-1/2 inch (38 mm) Hot Rolled		1-1/2 inch (38 mm) Cold Finished and Heat Treated	
F	C	ft-lbs	Joules	ft-lbs	Joules	ft-lbs	Joules	ft-lbs	Joules	ft-lbs	Joules
-60	-51	--	--	--	--	7	9-1/2	--	--	--	--
-40	-40	2	3	1-1/2	2	12	16	4	5-1/2	3	4
-40	-40	--	--	1-1/2	2	10-1/2	14	--	--	3	4
-20	-29	--	--	--	--	42-1/2	58	--	--	--	--
0	18	3-1/2	5	2	3	59-1/2	81	12	16	6-1/2	9
0	18	--	--	2-1/2	3-1/2	--	--	13	17-1/2	7	9-1/2
32	0	8	11	4	5-1/2	55	75	33	45	16-1/2	22
32	0	6-1/2	9	3-1/2	5	--	--	34	46	21	28-1/2
55	13	9-1/2	13	7	9-1/2	--	--	--	--	31-1/2	43
55	13	--	--	5-1/2	7-1/2	--	--	--	--	--	--
72	22	23	31	10-1/2	14	--	--	59-1/2	81	54	73-1/2
72	22	24-1/2	33	12-1/2	17	--	--	67	91	51	69
100	38	--	--	16-1/4	21	--	--	--	--	73	99
100	38	--	--	18-1/4	25	--	--	--	--	--	--
123	51	30	41	35	47-1/2	--	--	68	92-1/2	77	105
123	51	31	42	32	43-1/2	--	--	72	98	--	--
164	73	30-1/2	41-1/2	41	56	--	--	--	--	68	92-1/2
209	98	--	--	37	50	--	--	--	--	74-1/2	101

Table V. Shear Fracture Appearance Data Summary

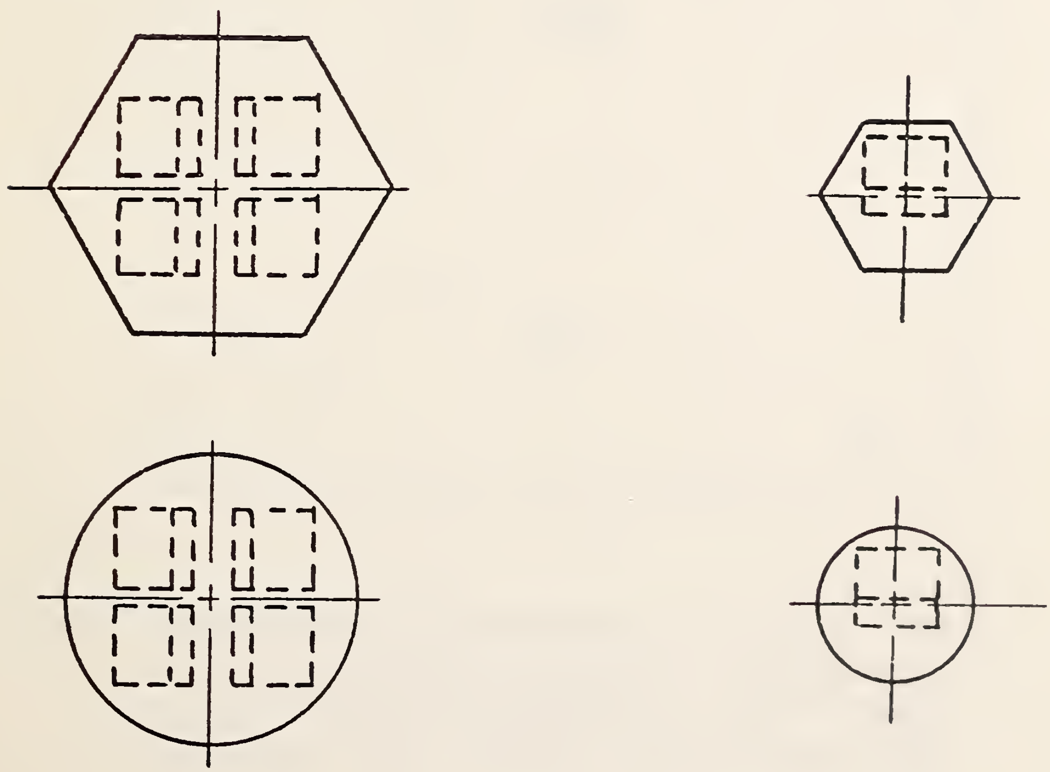
Test Temperature F	Test Temperature C	3/4 inch (19 mm) Cold Finished %	1-1/2 inch (38 mm) Cold Finished %	3/4 inch (19 mm) Hot Rolled %	1-1/2 inch (38 mm) Hot Rolled %	1-1/2 inch (38 mm) Cold Finished and Heat Treated %
-60	-51	--	--	5	--	--
-40	-40	0	0	20	5	2
-40	-40	--	0	15	--	2
-20	-29	--	--	65	--	--
0	18	0	0	90	15	10
0	18	--	0	--	15	15
32	0	7	3	98	50	25
32	0	5	5	--	50	30
55	13	20	10	--	--	40
55	13	--	10	--	--	--
72	22	60	20	--	95	70
72	22	55	25	--	97	65
100	38	--	45	--	--	90
100	38	--	50	--	--	--
123	51	98	80	--	100	95
123	51	99	80	--	100	--
164	73	100	98	--	--	100
209	98	--	100	--	--	100

Table VI. Summary of Transition Temperature and Upper Shelf Behavior

Size and Condition	Upper Shelf Energy Absorption ft-lbs	Joules	Energy Absorption Transition Temperature F	C	Shear Fracture Appearance Transition Temperature F	C
3/4 inch (19 mm) Cold Finished	31	42	+63	+17	+72	+22
1-1/2 inch (38 mm) Cold Finished	38	52	+93	+34	+102	+39
3/4 inch (19 mm) Hot Rolled	58	79	-32	-36	-22	-30
1-1/2 inch (38 mm) Hot Rolled	70	95	+6	-14	+32	0
1-1/2 inch (38 mm) Cold Finished and Heat Treated	75	102	+27	-3	+62	+17



a.



b.

Figure 1. Schematic of Test Specimen Location and Orientation

a. Tensile Test Specimens
b. Charpy V-notch Impact Specimens

a.

b.

Figure 2. Representative Photomicrographs of Inclusion Pattern

a. 3/4 inch (19 mm) hexagonal bar, cold finished
b. 1-1/2 inch (38 mm) hexagonal bar, cold finished

Longitudinal Plane Unetched Magnification: X100

c.

d.

Figure 2. (Cont)

c. 3/4 inch (19 mm) round bar, hot rolled
d. 1-1/2 inch (38 mm) round bar, hot rolled

Longitudinal Plane Unetched Magnification: X100

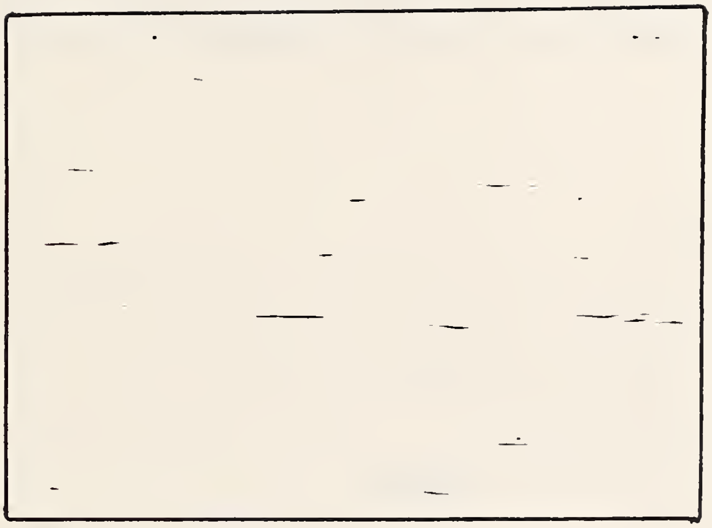
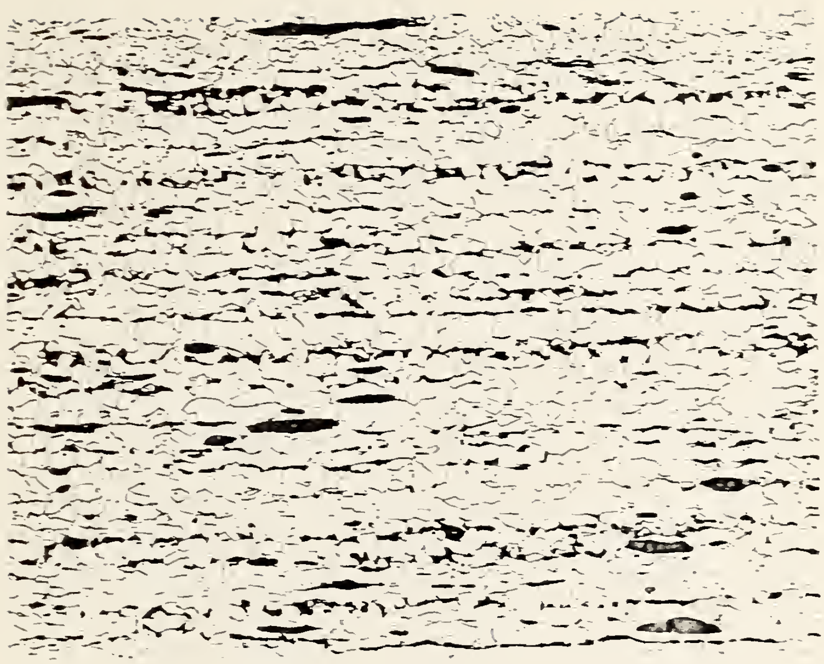


Figure 3. Representative Photomicrograph of a Low Sulfur Steel (0.017% S) Longitudinal Plane Unetched Magnification: X100



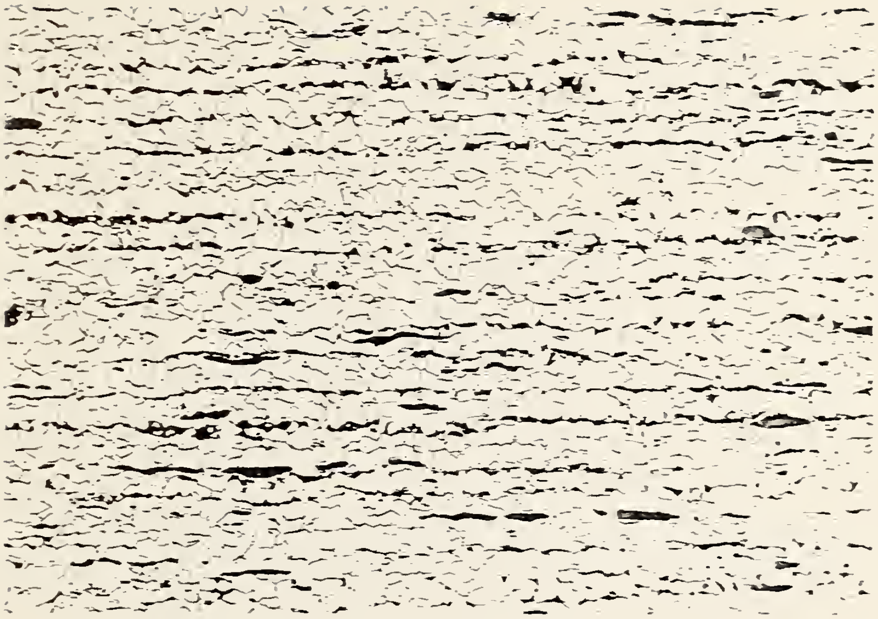
a.

b.

Figure 4. Photomicrographs of Typical Etched Microstructures

a. 3/4 inch (19 mm) hexagonal bar, cold finished
b. 1-1/2 inch (38 mm) hexagonal bar, cold finished

Longitudinal Plane Etch: 2% Nital Magnification: X100



c.

d.

Figure 4. (Cont)

c. 3/4 inch (19 mm) round bar, hot rolled
d. 1-1/2 inch (38 mm) round bar, hot rolled

Longitudinal Plane Etch: 2% Nital Magnification: X100

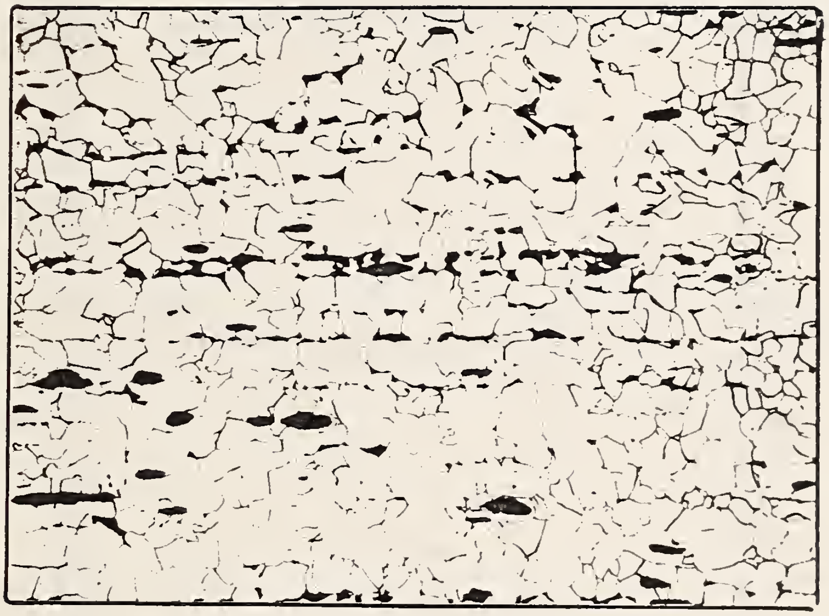


Figure 5. Typical Microstructure of Cold Finished/Heat Treated Bar
1-1/2 inch (38 mm) hexagonal Bar
Longitudinal Plane Etch: 2% Nital Magnification: X100

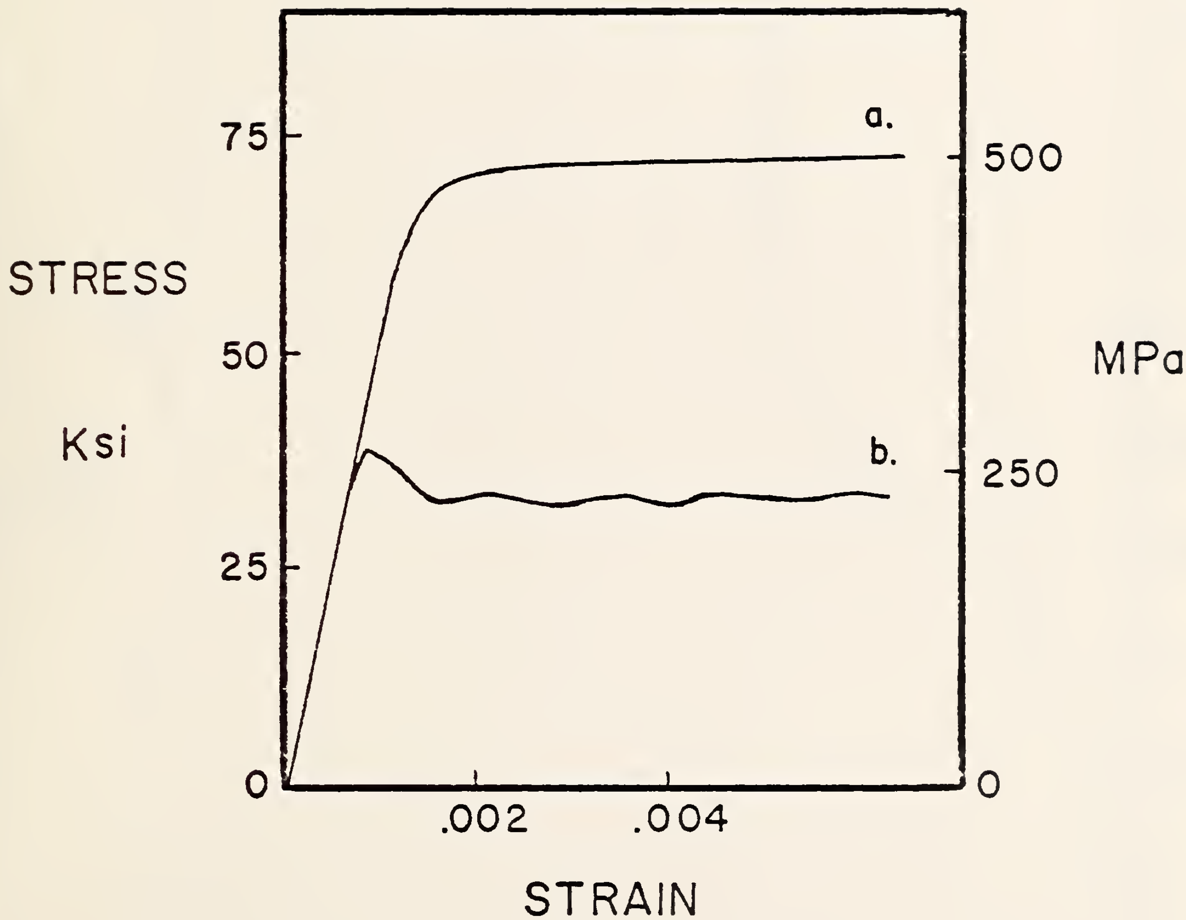


Figure 6. Schematic of Observed Engineering Stress-Strain Curves

a. Cold Finished Condition

b. Hot Rolled Condition; and Cold Finished/Heat Treated Condition

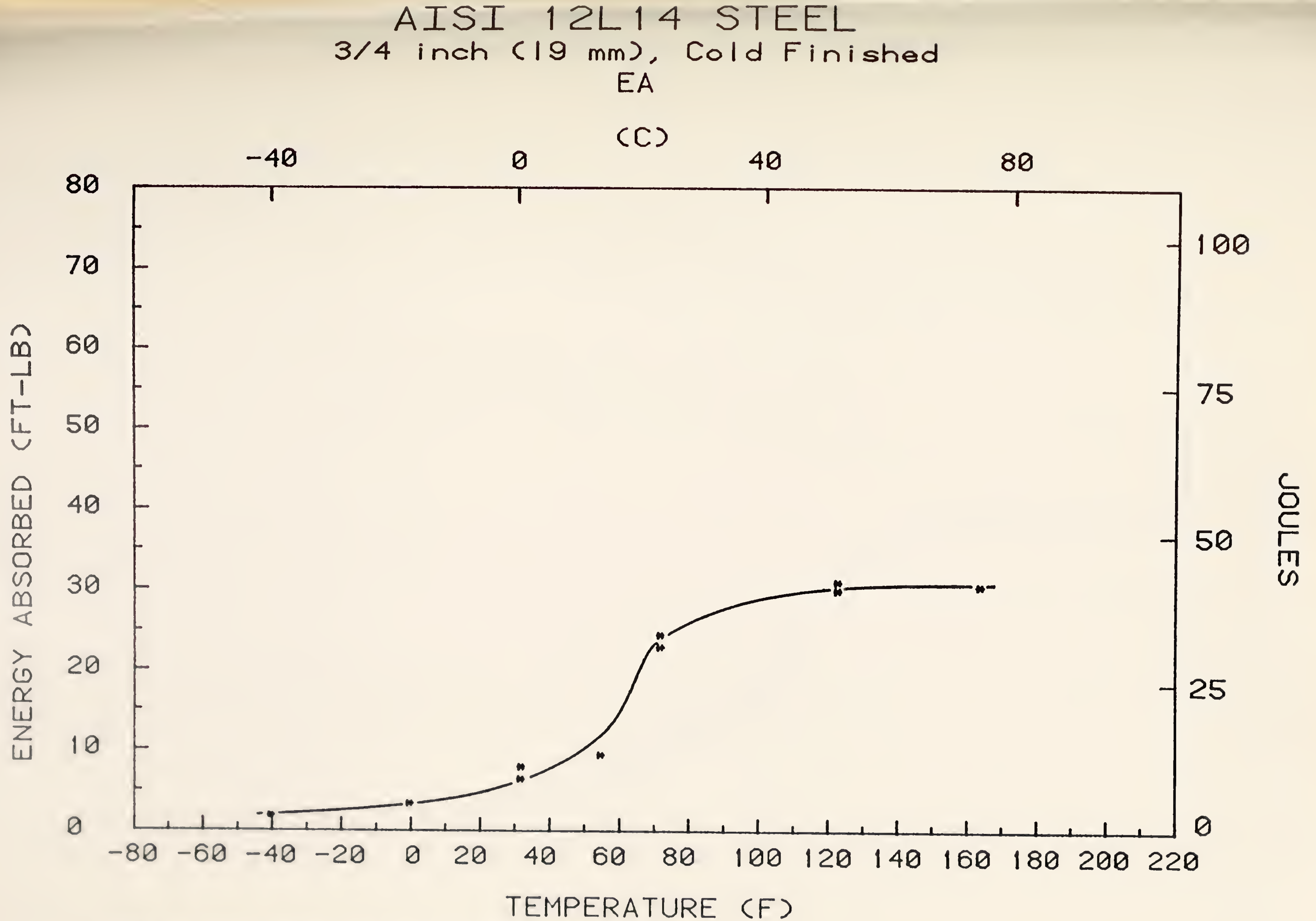


Figure 7a. Energy Absorption Temperature Transition Curve

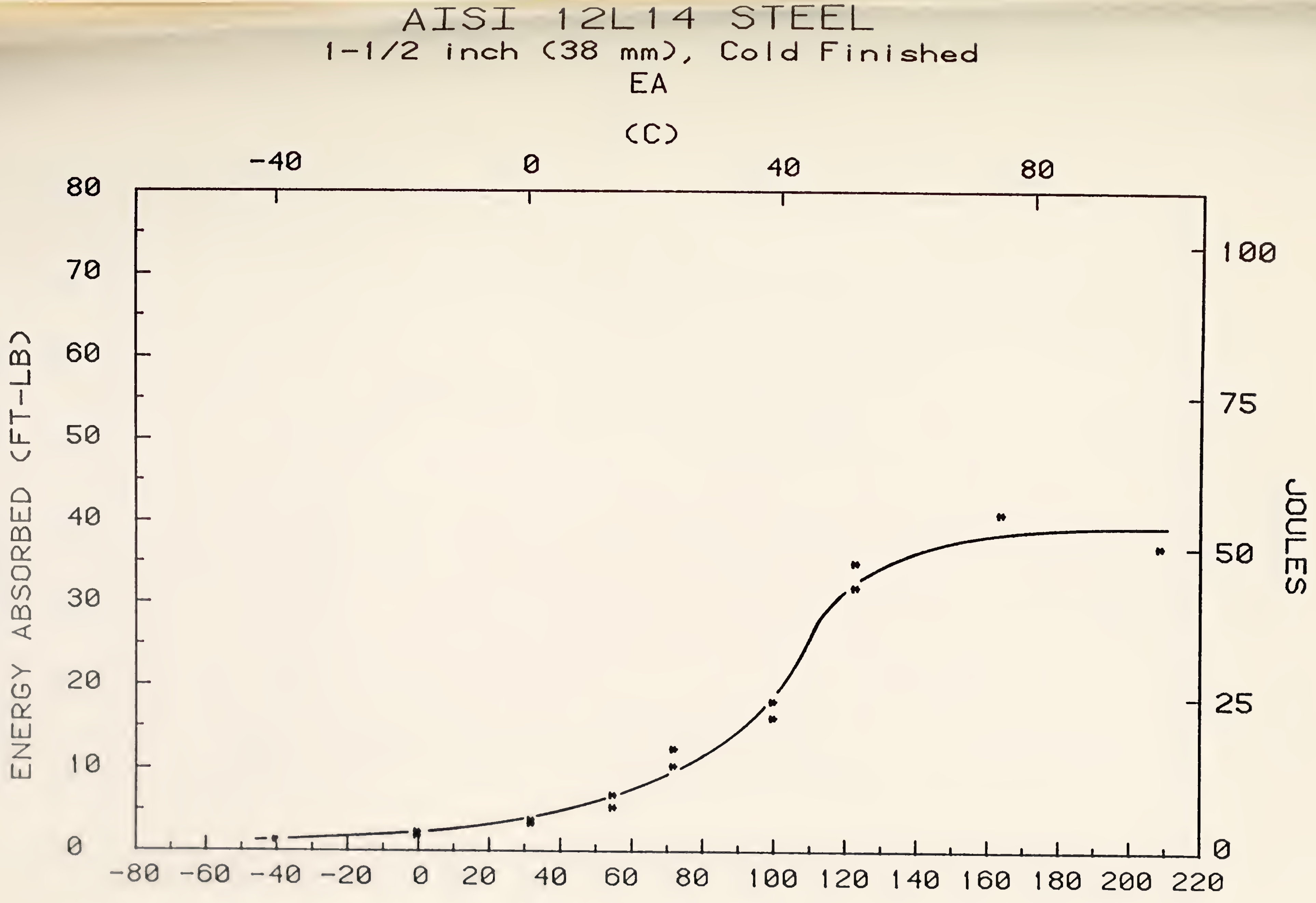


Figure 7b. Energy Absorption Temperature Transition Curve

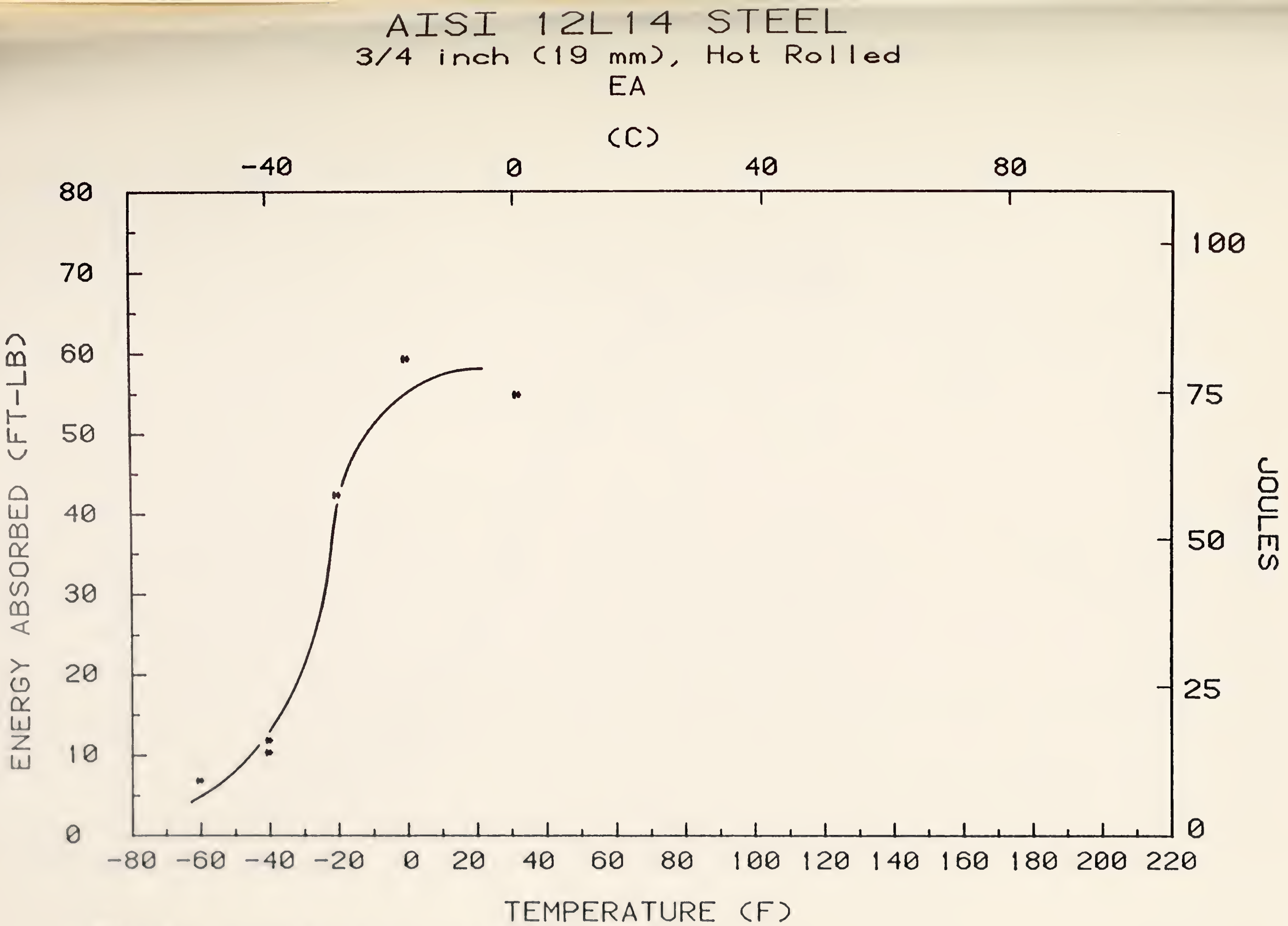


Figure 7c. Energy Absorption Temperature Transition Curve

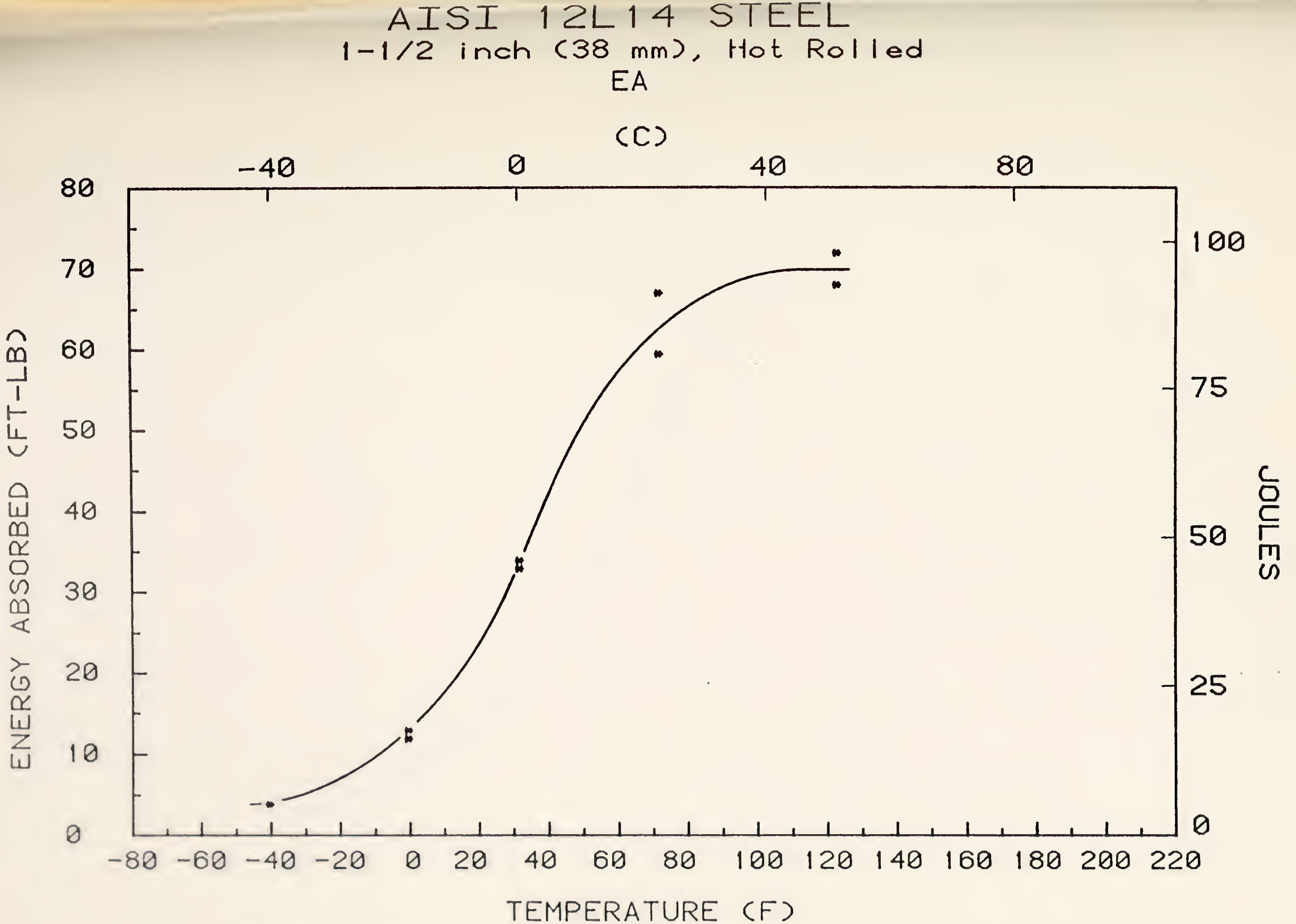


Figure 7d. Energy Absorption Temperature Transition Curve

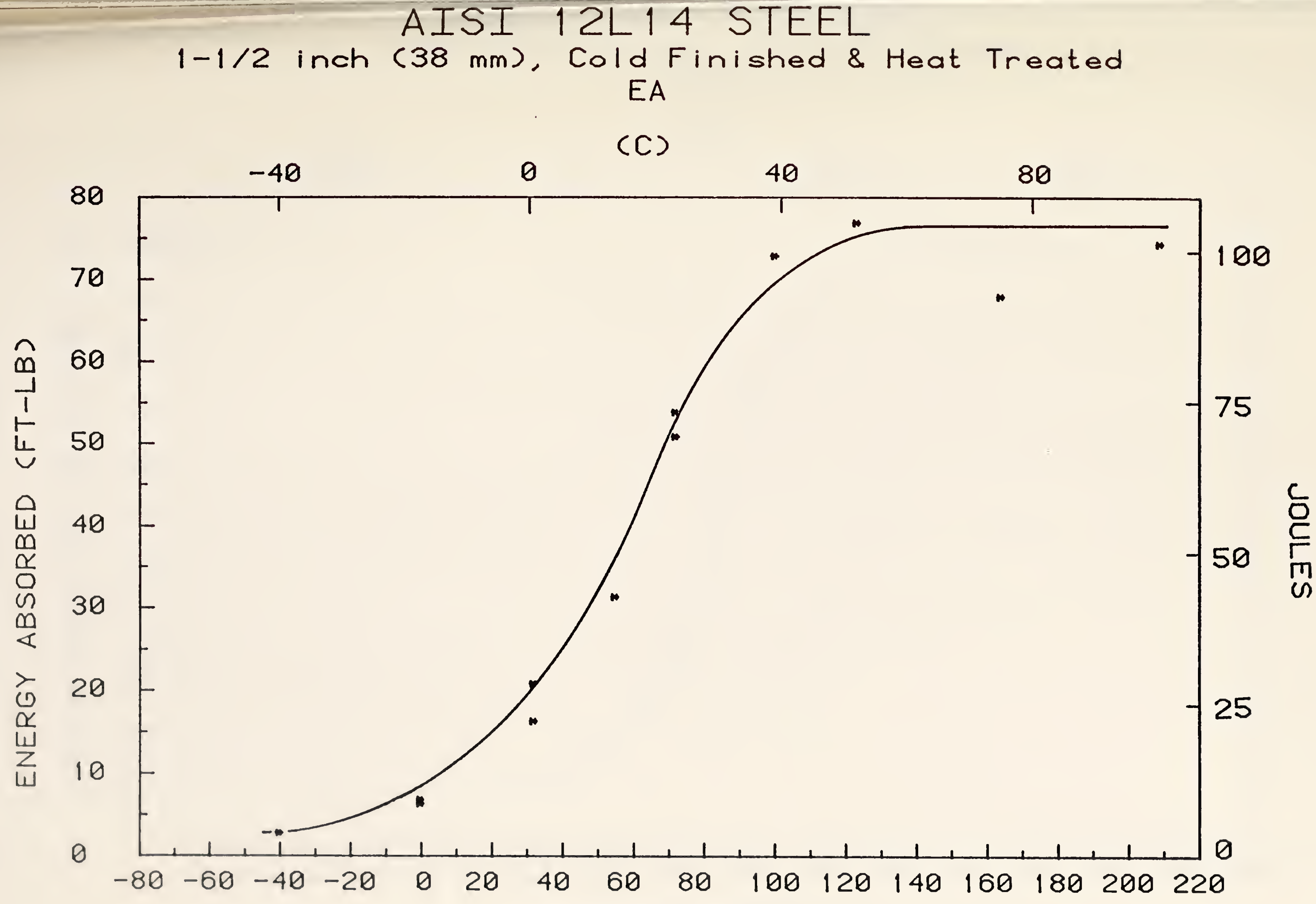


Figure 7e. Energy Absorption Temperature Transition Curve

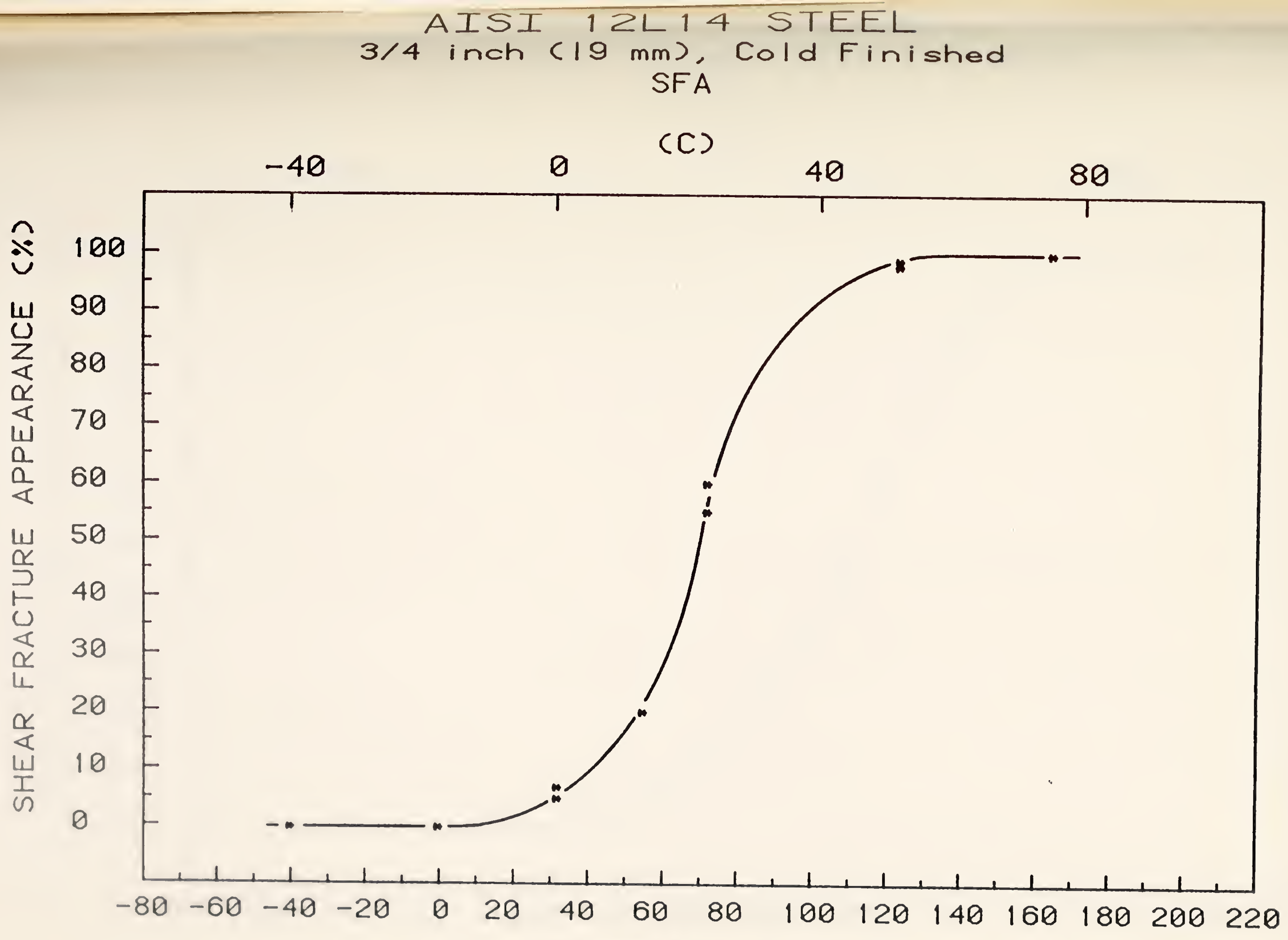


Figure 8a. Shear Fracture Appearance Temperature Transition Curve

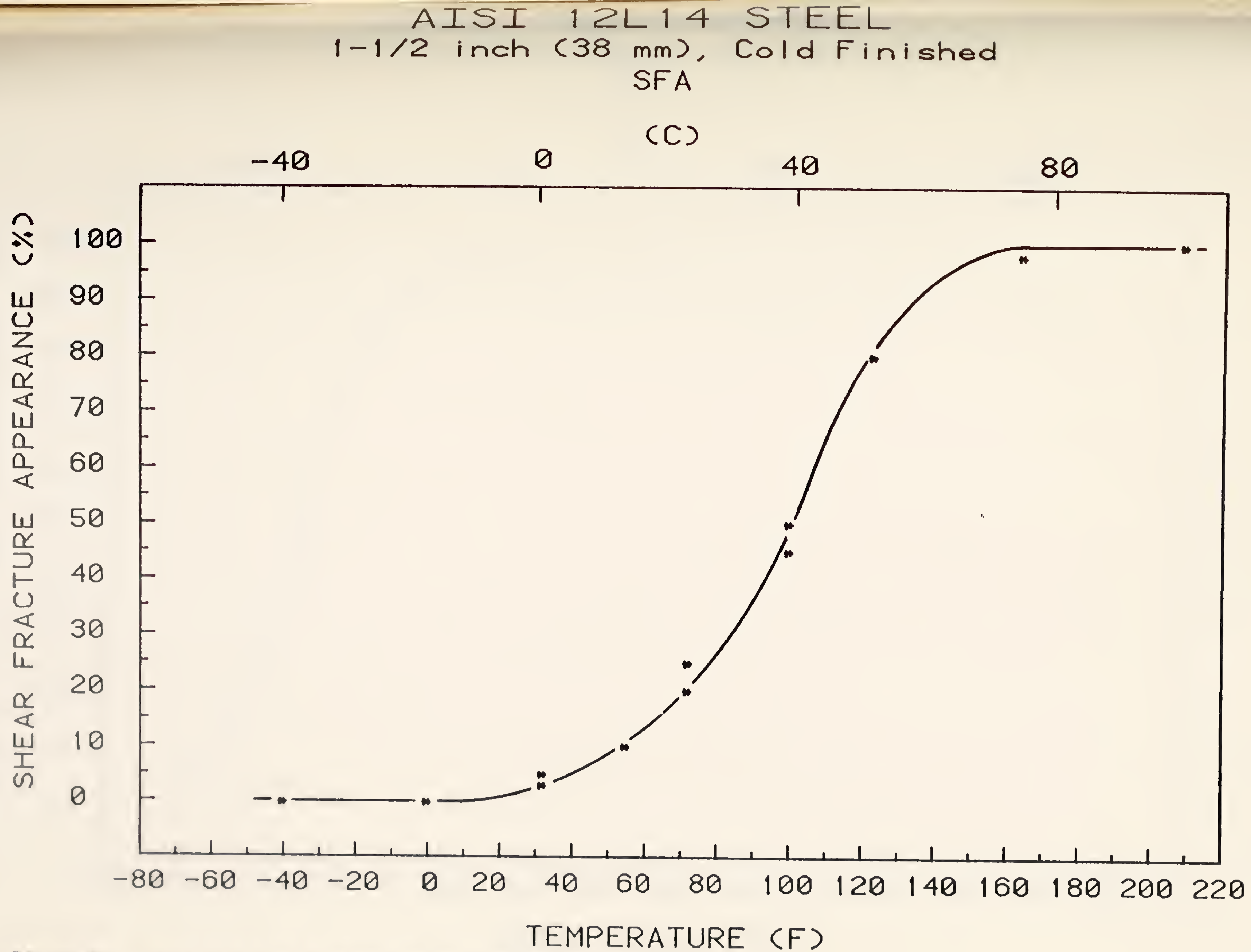


Figure [illegible]b. Shear Fracture Appearance Temperature Transition Curve

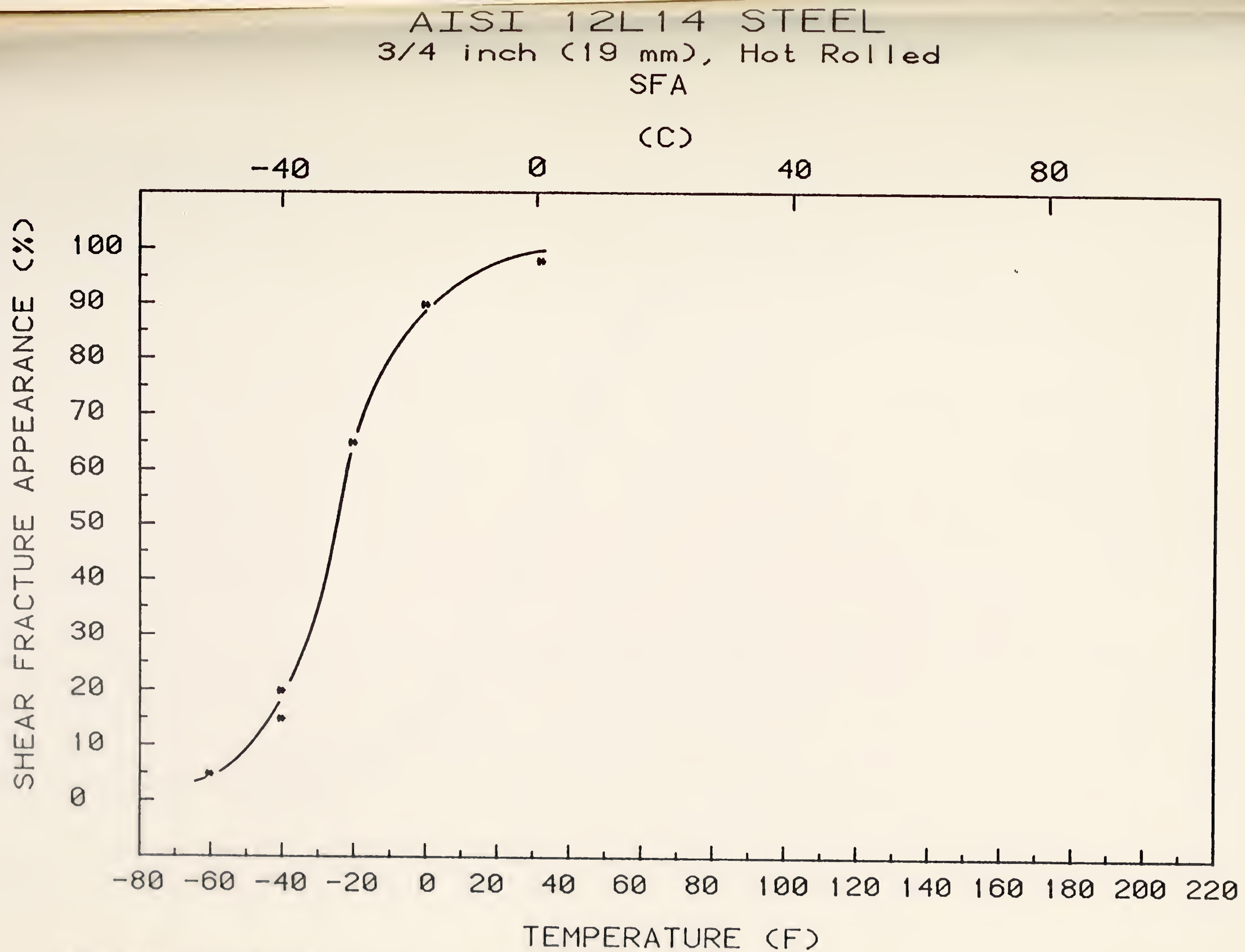


Figure 8c. Shear Fracture Appearance Temperature Transition Curve

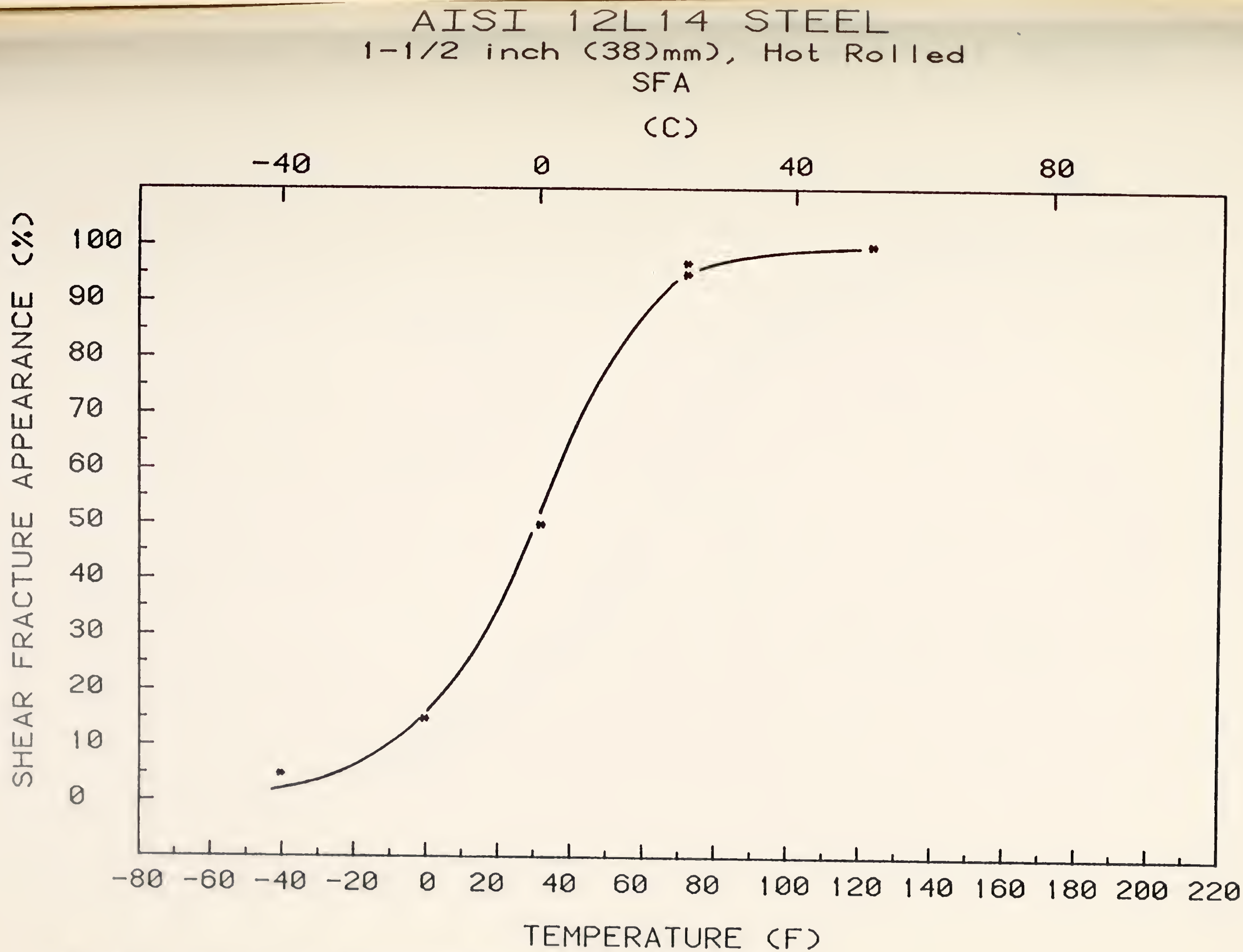


Figure 8d. Shear Fracture Appearance Temperature Transition Curve

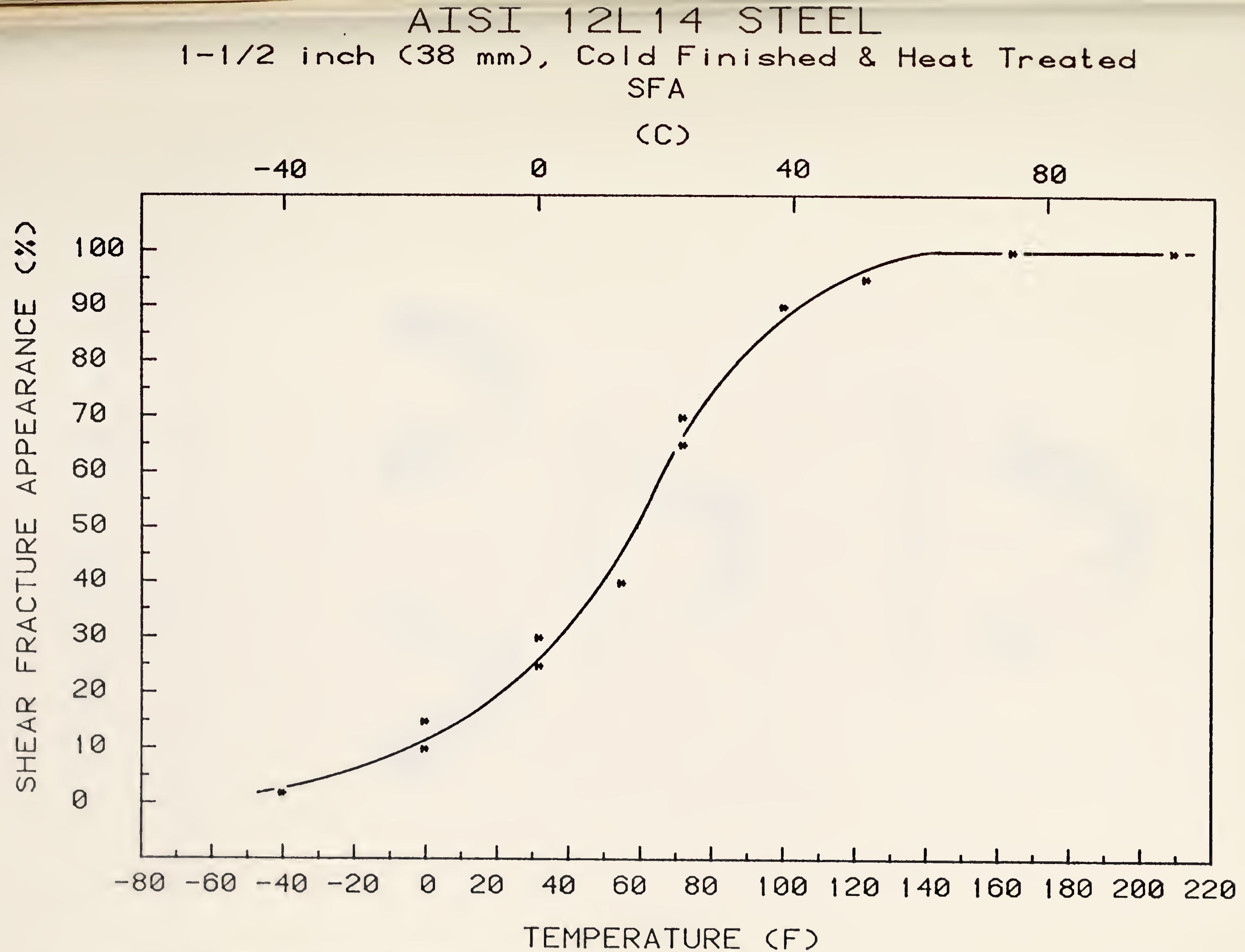
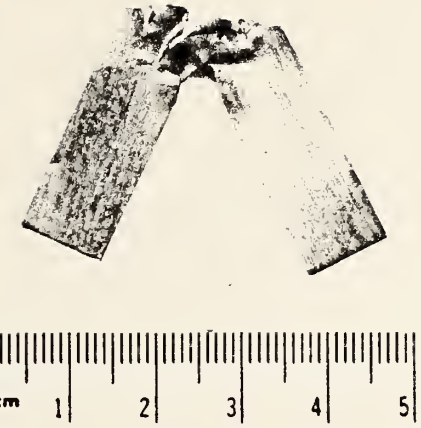
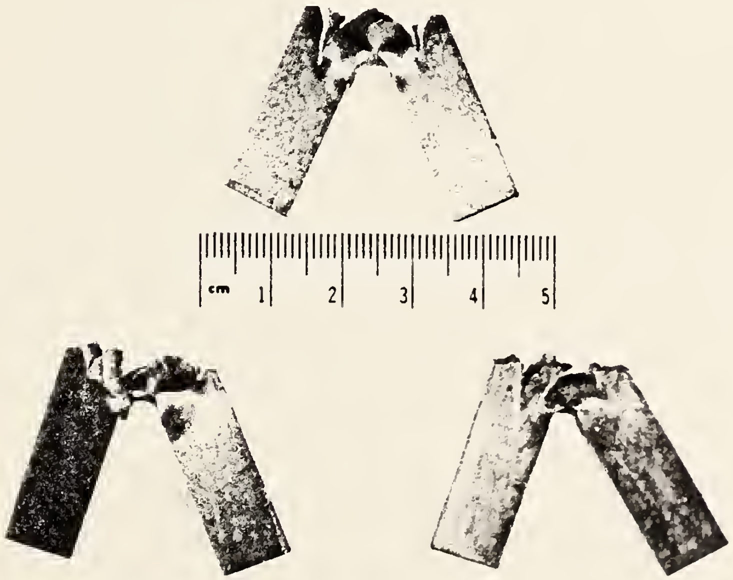


Figure 8e. Shear Fracture Appearance Temperature Transition Curve



a.



b.

Figure 9. Charpy V-notch Specimens Exhibiting Changed Fracture Mode

a. 1-1/2 inch (38 mm) hot rolled bar, Temperature = 164 F (73 C)
b. 3/4 inch (19 mm) hot rolled bars
   Top Row: Temperature = 55 F (13 C)
   Bottom Row: Left, Temperature = 72 F (22 C)
   Right, Temperature = 123 F (51 C)

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
	NBSIR 84-2839		March 1984

4. TITLE AND SUBTITLE

Mechanical Properties of a Leaded, Resulfurized, Rephosphorized Steel in Various Thermo/Mechanical Conditions

5. AUTHOR(S)

James G. Early

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

Z70099-2-02055

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

U. S. Coast Guard
Washington, DC 20234

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The results of the metallurgical evaluation of bar stock samples of AISI 12214 steel in two thermo/mechanical conditions, cold finished and hot rolled, illustrate the dominant role that the thermo/mechanical condition has on the resulting mechanical properties. The contributing effects of ferrite grain size and bar diameter on mechanical properties were small in comparison to the effects of cold work during the cold finishing operation. Cold finished bar stock samples subjected to a thermal brazing cycle (without the brazing alloy) develop mechanical properties that are very similar to those attained in hot rolled bars.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

bars, cold finished, cold finished/heat treated, hot rolled, leaded steel, rephosphorized steel, resulfurized steel.

13. AVAILABILITY

XX Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

XX Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

[illegible]8

15. Price

[illegible]